APPENDIX C

CANISTERED FUEL PHYSICAL CHARACTERISTICS

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CANISTERED FUEL PHYSICAL CHARACTERISTICS

C.1 CANISTER CHARACTERISTICS NOT EXPECTED TO VARY OVER TIME

C.1.1 NONDISPOSABLE CANISTERS (SINGLE AND DUAL-PURPOSE CANISTERS)

Information to be developed for subsequent revision.

C.1.2 PROBLEMATIC SNF IN DISPOSABLE CANISTERS

Categories of CSNF projected to be placed into disposable canisters (defined as canisters that can be placed into disposal containers without being repackaged) include:

- Mechanically and Cladding-Penetration Damaged SNF - SNF classified by waste Purchasers as failed because of (1) mechanical damage that limits the ability to vertically lift the assembly, or to fit within the dimensional envelope of standard fuel, and/or (2) "known or suspected cladding defects greater than a hairline crack or pinhole leak" as defined in the NRC Staff Guidance on Damaged Fuel (NRC 1998).

- Consolidated/Reconstituted Assemblies - SNF assemblies that were disassembled and, if reassembled, were done so in a form that is dimensionally different from the original.

- Fuel Rods, Pieces, and Debris - Variable-sized pieces of fuel (ranging from a single pellet to a full rod) and debris combining fuel and nonfuel materials.

- Nonfuel Components - Includes in-core assembly components physically separated from the assemblies and shipped separately.

Assumptions used in the estimates provided below include:

- Existing canistered waste (excluding multi-element canisters) can be transported in accordance with 10 CFR 71 and will not be repackaged by the Purchaser.

- All canistered failed assemblies and fuel debris are in either unsealed screen-end canisters or sealed solid-end canisters, both comparable in size to that of uncanistered assemblies (i.e., they fit into racks in reactor pools). No sealed canisters will be used for failed assemblies.

- All canisters can be handled like uncanistered SNF at that reactor site (similar crane hook interface).

- Existing/projected non-integral nonfuel components will be delivered to the CRWMS (not sent to a low-level waste disposal facility, as is currently done by certain utilities).

- All but a small fraction of nonfuel components will remain integral to the assembly (excluding non-integral items physically removed from the assembly to meet the assembly dimensional or weight requirements for transport).

C.1.2.1 Existing Quantities of Canistered SNF Assumed to Be Disposable

Materials currently canistered for containment or handling reasons will be delivered "as is" unless 10 CFR 71 precludes transport. Given the assumption that all existing canistered wastes will meet 10 CFR 71 and will not be repackaged prior to transport, this means currently canistered materials are treated as disposable in this report. This disposability assumption does not apply to multi-element canisters used at utility sites for long-term storage.

Specific canister-handling data are currently unavailable in CRWMS databases. This includes the physical construction of the canister (e.g., are the ends screened?), the degree to which these canisters can be loaded in a disposal container without repackaging (e.g., are free liquids removed?), and the ease with which the canister can be handled. (Are handling fixtures permanently attached, how easily are they attached if not permanently part of the assembly, and what impact does the addition of the handling fixture have on the overall canister dimensions?) Existing information in CRWMS databases include the number of canisters of waste, the canister physical dimensions, and a qualitative assessment of canister contents relative to the canistered SNF categories described above. This section covers existing canisters of wastes. Existing (but currently uncanistered) wastes to be canistered before transport, or wastes to be generated and canistered in the future, are addressed in Section C.1.2.2.

Data reported by Purchasers through December 31, 1994, list 265 canisters of material in commercial inventories (DOE 1996). These canisters are subdivided as follows:

- 145 canisters of fuel only (intact assemblies, intact rods, rod pieces, pellets, fuel debris)
- 101 canisters of nonfuel components only
- 19 canisters of a mixture of fuel and nonfuel materials.

Canisters containing only fuel or a mixture of fuel and nonfuel components are equally distributed between those containing an assembly and those with only "loose" fuel (ranging from intact rods to debris). Precise counts are 42 canisters with intact assemblies, 87 canisters with rods and pieces (up to 31 may contain an assembly plus rods/pieces), 31 canisters with consolidated assemblies, and 4 canisters with "unknown" contents (DOE 1996, Table 16).

Dimensionally, these canisters are diverse but fit within assembly dimensional envelopes. Most range in cross-section from 5 x 5 inches to 9 x 9 inches, and in length from 138 inches to 189 inches. There are 13 canisters with no dimensions reported (all are assumed to fall within the 5 to 9 inch and 138 to 189 inch envelope). Various sizes are widely distributed among Purchaser sites. Table C-1 lists canisters with reported dimensions outside these ranges.

Table C-1. Existing Canisters with "Non-Standard" Dimensions [a]

Reactor Name	Number of Canisters	Canister Contents	Canister Length (inches)	Cross-Section (inches)
Palo Verde 1 & 2	2	Fuel Rods	180	1 x 1
Arkansas Nuclear 2	1	Fuel Rods/Pieces	176	16 x 16
Calvert Cliffs 1 & 2	16	Nonfuel Debris	148	2 x 2
Byron 1 & 2	4	Assemblies	170	19 x19
Big Rock Point	3	Partial Fuel Rods	60	12 x 12
Big Rock Point	2	Fuel Pieces	18	12 x 12
Big Rock Point	2	Fuel Rods	84	6 x 0[b]
Fermi 2	4	Nonfuel Components	180	36 x 0[b]
McGuire 1	1	Single Fuel Rod	170	10 x 10
Beaver Valley	2	Fuel Rods	170	14 x 14
Oconee 1 & 2	6	Fuel Rods	170	10 x 10
Millstone 2	2	Single Fuel Rod	171	3 x 3
Prairie Island 1 & 2	2	Nonfuel Components	159	5 x 5
Humboldt Bay	1	Assembly	84	12 x 12
Point Beach 1 & 2	1	Single Fuel Rod	180	10 x 10
Total Fuel	**27**			
Total Nonfuel	**22**			

NOTES: [a] DOE 1995b.
[b] Devotes a cylindrical container, with diameter = the non-zero value.

It should be assumed that all existing canisters that meet the following criteria will be transported "as is":

- Meet the dimensional requirements for baskets in existing or projected transport casks
- Have screened ends (assumed to be all canisters in pool storage)
- Have intact lifting fixtures that allow the canister to be safely lifted vertically by the same equipment used to lift uncanistered intact assemblies.

C.1.2.2 PROJECTED QUANTITIES OF CANISTERED SNF

Projected quantities of canistered SNF include existing materials not yet canistered (e.g., to meet 10 CFR 71 requirements for transportation) and SNF projected to be generated and canistered in the future. For existing materials, projections depend on which "failed" assemblies need to be canistered. These projections easily vary by two orders of magnitude depending on how failure modes are classified. A recent proposed classification (EPRI 1997) groups failure modes into those involving assembly mechanical damage (failure of handling fixtures or distortions in assembly dimensions), and cladding penetration and damage. Both failure modes are further subdivided into minor and major. Assemblies with "major" mechanical or cladding failure are rare and must be canistered to be handled at the Purchaser site. They also must be canistered for transport, as the NRC routinely includes in transport cask certificates of compliance the provision that failed assemblies (other than those with pinhole leaks or minor cracks) be canistered prior to transport.

Some fraction of failures are borderline, and it is recognized that most failed assemblies may be stored for a number of years. It is possible that a current inconsequential failure may become more problematic over time. Data on the long-term degradation of "failed" assemblies aren't definitive, so estimates of the number of these assemblies that will be "major" failures at the time of transport are uncertain. There is also the issue of assembly damage during cask loading. It is assumed, for the purposes of this study, that 15 percent of the assemblies currently identified as "failed," but whose failure is currently considered minor, will be canistered prior to transport. EPRI, 1997, estimates 10-20 percent of assemblies designated as failed to be "intermediate" between pinhole/hairline-crack failure and visible failure. This estimate covers any assemblies damaged during handling activities at the Purchaser site.

C.1.2.2.1 Existing Uncanistered "Failed" Fuel Requiring Canistering

Estimates of existing failed assemblies are 4,864 to 9,728 assemblies (EPRI 1997). Of these, roughly 50-100 are severe failures (EPRI 1997) and are assumed to be part of the existing canistered-waste inventory. Subtracting the severe failures and applying the 15 percent intermediate-failure assumption yields 700-1,400 assemblies. It is assumed, for the purposes of this study, that 1,100 existing assemblies will have sufficient mechanical or cladding damage to justify canistering. It should be noted, however, that this number represents a range of 500 (roughly 10 percent of 4,864) to 1,950 (roughly 20 percent of 9,728), and that any conceivable fraction of these "intermediate-failure" assemblies may be safely handled and transported without being canistered. It is assumed that these assemblies will be placed into unsealed single-element canisters.

C.1.2.2.2 Projected Canistered "Failed" Fuel

Current and projected trends in Purchaser handling of "failed" assemblies are based only on the more recent operational data because of improved operations over time. For example, failed assemblies discharged prior to 1986 averaged 2.2 failed rods per assembly (EPRI 1997), which suggests that the vast majority of the fuel cladding in the assembly remains intact. More recently, Purchasers are replacing failed rods, reinserting the "repaired" assembly, and collecting the failed fuel into canisters or reconstituting them into assemblies with exclusively failed rods. Whereas most historical failed assemblies are "minor" failures, the majority of projected failed assemblies will have more extensive problems.

Rough projections of the "to be generated" failed CSNF are based on the following assumptions:

- There will be no significant improvement in assembly failure rates in the future (use of current failure rates to generate projections is conservative but reasonable).

- The split between canisters containing intact assemblies and loose rods or fuel debris will continue to reflect historical trends (a roughly 50-50 split).

- Canisters containing individual rods and fuel debris will contain the equivalent of 20 percent of the fuel in a full assembly.

- An additional 46,900 MTU will be generated between 1998 and 2035 (36,900 MTU exists now, for an estimated total of 83,800 MTU in 2035). [*Calculation Method for the Projection of Future SNF Discharges* (Draft). A000000000-01717-0200-0052 REV 00, Vienna Virginia: CRWMS M&O. ACC: MOV.19990625.0001.]

- Each of the 104 currently operating reactors will have some failed rods, and reactors that share a pool can combine failed rods into a single canister or reconstituted assembly.

- Failed fuel will be shipped to the repository from each Purchaser storage site four times over the waste-emplacement life of the repository (roughly once every 10 years).

Reference EPRI 1997 states that the current fuel rod failure rate is about 0.01 percent (versus 0.02 - 0.07 percent in the first 20 years of commercial nuclear power). The projected 46,900 MTU of SNF to be generated translates into 163,700 assemblies [*Calculation Method for the Projection of Future SNF Discharges* (Draft). A000000000-01717-0200-0052 REV 00. Vienna, Virginia: CRWMS M&O. ACC: MOV.19990625.0001]. If all failed rods are removed from the original assemblies and reconstituted as failed assemblies without regard to time or geographic location, this would yield only 16-17 failed-assembly equivalents (163,700 assemblies x 0.01 percent). Note that this represents a theoretical minimum only, as there are 104 operating reactors, and failures will be distributed over each reactor's remaining operating life. As a point of reference, distributing the failed-assembly equivalents evenly among the 72 existing storage sites yields 0.23 assembly-equivalents per site (16.37 assemblies divided by 72 sites). The following logic results in a more realistic estimate.

- There will be a minimum of four reconstituted assemblies (using only failed rods) per storage site. This results in 288 reconstituted assemblies, to address "minor" cladding penetration damage (reasonable given that the theoretical minimum site average is only 0.23 canister equivalents over 40 years).

- There will be an average of two canisters of fuel debris per site per each 10 years of repository emplacement operations (8 per site times 72 sites). This is based on the assumption that some of the damaged rods will simply be placed into a canister, rather than reconstituted into the "failed-fuel" assembly addressed in the previous bullet.

- There will be an average of 2.3 canisters per site for assemblies with "major" mechanical damage (corresponds to roughly one-tenth of 1 percent of the 163,700 assemblies to be generated) or for assemblies identified as failed and simply discharged.

This yields a total projection of approximately 1,000 unsealed canisters of failed fuel to be delivered to the CRWMS (14.3 canisters per site times 72 sites). It can be assumed that all of these canisters will be screened-end containment vessels essentially identical to those currently in use and dimensionally compatible with an uncanistered assembly. Given that cask owners have the option of using sealed canisters (none currently reside in commercial utility pools), some small fraction of the projected 1,000 canisters may be sealed (solid end) canisters that need handling through the canister transfer system.

It should be noted that the total projection of approximately 1,000 canisters of failed fuel is consistent with the historical data. Assuming 46,900 MTU of SNF will be generated and 36,900 MTU has been generated to date, the ratio of generated to projected is 46.9 to 36.9 or 1.27 to 1. There are currently 164 existing canisters containing fuel, a maximum of 300 canister equivalents of fuel currently reported as “in baskets,” and 1,100 assemblies designated as “failed” (see Section C.1.2.2.1). Applying the 1.27:1 ratio yields roughly 2,000 projected canisters. Recognizing that there was a much higher assembly failure prior to 1981 and more at-reactor research/testing that generated wastes needing canistering, a ratio of roughly 2:1 between existing and projected inventories appears reasonable.

C.1.2.2.3 Projected Canisters of Other Existing Uncanistered Fuel

Data reported by Purchasers through December 31, 1994, indicate that there are 300 “baskets” of material in commercial inventories (DOE 1996). These are primarily open baskets in reactor pools, although some are referred to as “sealed baskets.” Data on these baskets are incomplete, and it cannot be determined what quantities of materials are in each basket, the distribution between fuel and nonfuel components in each basket, or which of these might be double-counted canisters. Most likely, the contents of each basket will be placed into its own canister, with all canisters being the screened-end containment vessels essentially identical to those currently in use and dimensionally compatible with an uncanistered assembly. This translates to 300 canisters of currently “basketed” waste that will be delivered to the CRWMS. The alternative is that the SNF will be shipped in these “baskets” (this assumes that they are shippable per 10 CFR 71, which is unlikely). This indicates that the CRWMS may receive sealed baskets ranging in size from 12x12x36 (inches) to 1x1x180 (inches).

There are also a small number of “disassembled and reconfigured” assemblies (product of consolidation trials) that are currently stored uncanistered. Some are reconfigured into a larger assembly (two such assemblies exist at Maine Yankee) that still meet the dimensional definition of standard but don’t match any commercial fuel design. These assemblies are not specifically identified by the Purchasers in the RW-859 data sets (DOE 1996); therefore, there is no estimate on their number or condition. It is assumed that any existing uncanistered “reconfigured” assemblies can be safely handled “as is” and that any new “reconfigured” assemblies will be transported in canisters.

C.1.2.2.4 Projected Canisters of Nonfuel Components (Existing and Projected Nonfuel Components)

Three variables significantly influence the estimated number of nonfuel component canisters transported, with nonfuel components defined in (DOE 1996) as:

- Components used to initiate, control, and monitor the chain reaction in the core (neutron sources, control elements, burnable absorbers, in-core instrumentation, etc.).

- The nonfuel portion of a fuel assembly (often called guide tubes, water rods, grids, nozzles, etc.).

- Miscellaneous hardware used in the reactor core that is not a part of fuel assemblies (dummy assemblies, coupon trees, thimble plugs, etc.).

The first variable involves the degree to which these components remain integral to the assembly. The vast majority can remain integral. The EIA (DOE 1996) reports that approximately 91 percent of the nonfuel components are currently stored integral to the assemblies. There is usually a slight increase in assembly dimensions (size and weight) due to integral nonfuel components (e.g., adds 100-200 lbs. to the assembly weight); however, these components are already addressed in Section B.1.1 of this report. It is assumed that the maximum number of nonfuel components possible will remain integral to the assembly. It should be noted, however, that the estimated number of nonfuel canisters increases by a factor of 2 to 10 if nonfuel components are removed from the assembly and shipped separately (CRWMS M&O 1992).

The second important variable is the degree to which these materials are managed as low-level waste and never delivered to the CRWMS (e.g., Purchaser chooses to create additional pool storage by shipping these materials to a low-level waste disposal facility). It is conservatively assumed that all existing nonfuel components, except those at sites with exhausted pool storage prior to January 30, 1998, will be delivered to the CRWMS. It is assumed that these sites chose to make additional storage space available by shipping these materials to low-level disposal facilities rather than purchase additional dry storage capacity.

The third significant variable involves the method for canistering the non-integral nonfuel components. Different volume-reduction methods can significantly affect the number of components per canister and hence the total number of canisters. Estimates of the number of canisters containing nonfuel components easily vary by a factor of five or more under compacted versus uncompacted scenarios (CRWMS M&O 1992).

Purchasers reported 65,190 pieces of nonfuel components from 104,742 discharged assemblies through December 31, 1994 (DOE 1996). Of these components, approximately 6,500 pieces are reported as non-integral to the assemblies. Using the same 1.27:1 ratio of projected to actual discharges, this translates to a projected additional 8,300 non-integral nonfuel components to be generated by 2040. It must be recognized, however, that:

1. Some fraction of the existing materials are already canistered in the 101 reported canisters of nonfuel components and the 19 reported canisters of mixed fuel and nonfuel components.

2. Another fraction of these materials currently reside in the 300 baskets reported in reactor pool inventories.

3. Once the repository becomes operational, there will be little incentive to follow historical practices of shipping some fraction of this material to low-level waste disposal facilities. Therefore, total quantities of materials delivered to the CRWMS likely will increase.

The study *System Aspects of Non-Fuel Bearing Hardware within the CRWMS* (CRWMS M&O 1992) estimated the quantities of nonfuel components for 63,000 MTU of fuel under three scenarios (maximum integral nonfuel components, compacted but all non-integral, and uncompacted non-integral). The maximum integral case assumed that only the control-rod assemblies from CE System 80 PWR assemblies (Palo Verde), BWR control assemblies (cruciforms and bases), BWR neutron-source assemblies, and BWR instrumentation assemblies are non-integral. For the purposes of this study, the same assumption will be used, with the exception that it also is assumed that 1 percent of BWR fuel channels [matches historical percentage if Nine Mile Point is excluded (DOE 1996)] and 4.5 percent of all other nonfuel components are also non-integral [matches historical percentage of non-integral PWR components (DOE 1996)].

Extrapolating data from Table 1 in *System Aspects of Non-Fuel Bearing Hardware within the CRWMS* (CRWMS M&O 1992) yields estimated total quantities of canistered, non-integral nonfuel components, assuming existing plus projected inventories of 125,000 PWR assemblies and 167,000 BWR assemblies [*Calculation Method for the Projection of Future SNF Discharges* (Draft). A000000000-01717-0200-0052 REV 00. Vienna, Virginia: CRWMS M&O. ACC: MOV.19990625.0001]. These estimates are summarized in Table C-2.

Table C-2. Estimated Total Canisters of Nonfuel Components

Component Description	Projected Components	Dimension of Can (inches)	Components per Can	Total Cans
PWR Control Assy (CE Sys. 80) - Rod Sets	720 [c]	9x9 x 160	17	43
PWR Control Ass'y (CE Sys. 80) - Spiders	720 [c]	9x9 x 160	25	29
Other Misc. PWR Components [a]	5,625 [d]	9x9 x 160	12 [d]	470
BWR Control Assy - Cruciforms	5,400 [e]	9x9 x 160 [e]	2 [e]	~2,700 [e]
BWR Control Assy - Bases	5,400 [e]	10.6 (dia) x 177	8	680
BWR Neutron Source Ass'y	295 [f]	6x6 x 160	7	42
BWR Instrumentation Ass'y	2,270 [g]	6x6 x 160	44	52
Other Misc. BWR Components [b]	1,670 [h]	6x6 x 168	7	240
TOTAL	21,700			~4,300 [i]

NOTES: [a] Includes control-rod assemblies other than those for CE System 80, burnable poison assemblies (rods and spiders), neutron source assemblies (rods and spiders), in-core instruments, and thimble plug assemblies (rods and spiders).
[b] Includes fuel channels.
[c] Assumes 1 control assembly for each 10 Palo Verde assemblies discharged (approximately 7,200 projected through 2040).

Table C-2. Estimated Total Canisters of Nonfuel Components (Continued)

[d] Represents 4.5 percent of assumed total 125,000 discharged PWR assemblies through 2035, and a canister loading of 12 pieces per canister.
[e] Assumes ratio of 1 control assembly for each 100 discharged BWR assemblies prior to 1998 (total of 700 control assemblies), and 5 control assemblies for each 100 discharged BWR assemblies thereafter (total of 4,700); also assumes that cruciforms will be cut into two L-shaped pieces and stacked so that four cut halves fit into a 9 in. by 9 in. canister (placement into larger cans will reduce total number of canisters).
[f] Assumes historical ratio of 1.77 neutron sources per 1,000 discharged BWR assemblies (DOE 1996) for projected 167,000 total BWR assemblies.
[g] Assumes historical ratio of 1.36 instrumentation assemblies per 100 discharged BWR assemblies (DOE 1996) for projected 167,000 total BWR assemblies.
[h] Uses 1 percent assumption and projected total BWR discharge of 167,000 assemblies.
[i] Should be reduced by 100 to account for existing canisters of nonfuel components.

Loaded canisters are projected to weigh from roughly 300 lbs. for BWR neutron source assemblies to approximately 2,500 lbs. for PWR control-rod-assembly rod sets (CRWMS M&O 1992).

C.2 PARAMETERS PROJECTED TO VARY OVER TIME

There are no data indicating whether single-element-sized canisters of SNF will be given priority shipment (i.e., remove the more problematic SNF from a site first) or left for last (not shipped until canisters are filled as much as possible before shipment). Given that these canisters are dimensionally interchangeable with bare assemblies, MGR annual receipt rates or variations in these rates should have no impact on facility design unless there is a different protocol or greater difficulty in drying these canisters prior to loading into disposal containers.

There is no design basis receipt rate assumed at this time for multi-element disposable canisters.

C.3 ADDITIONAL DESIGN CONSIDERATIONS

As with off-normal physical conditions for assemblies, there is a remote possibility that single-element-size canisters loaded undamaged into transport casks will either be jammed in the cask basket or otherwise damaged during transport. The conservative assumption that should be used in design is that there will be one cask shipment per year with at least one damaged canister that was undamaged prior to transport. An additional conservative assumption that should be used in design is that biennially one cask shipment will have a problem that requires the cask be taken off-line and remediated on a case-by-case basis.

There is some question regarding existing loaded storage canisters being granted a 10 CFR 71 exemption to enable them to be transported without being repackaged. These canisters are dimensionally similar to canisters licensed as DPCs; therefore, there should be no special consideration required relative to Surface Facility design.

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